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(54) Optical packet switching

(57) An optical packet is provided with an amplitude modulated (ASK) payload (11) and a differential phase shift keyed (DPSK) header (12) so that a routing address in the header can be read and modified at a network node without having to inject light at this node to do this modification. With ASK, though it is easy to convert a high-level bit to a low-level bit by simple attenuation, the conversion of low-level bit to high-level bit requires light injection. With DPSK, bit conversion can be effected without light injection, merely requiring passage through a phase modulator (29).

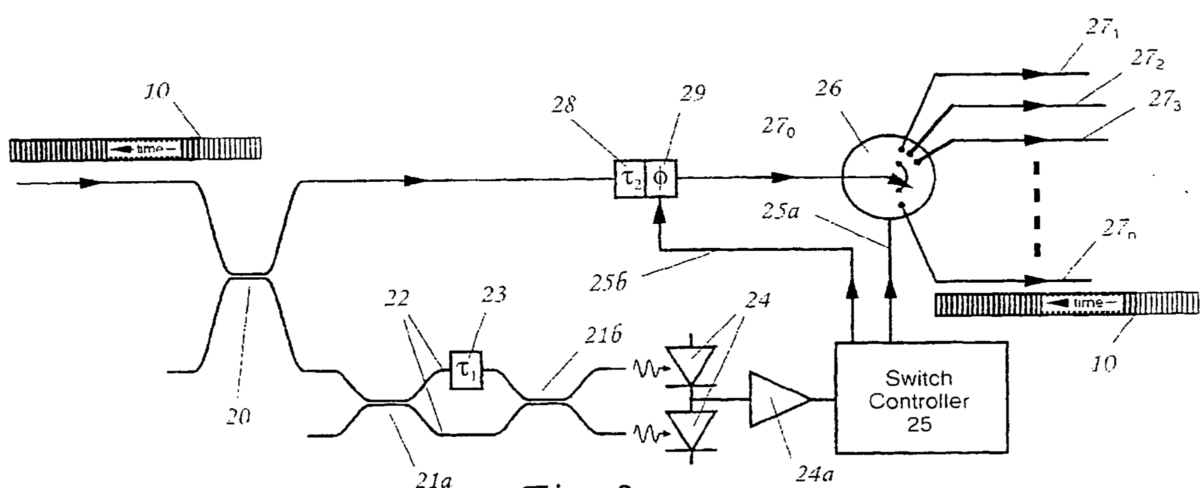

Fig. 2.

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Description

BACKGROUND TO THE INVENTION

[0001] This invention relates to the field of optical signal processing, and in particular to the processing of packet-based optical signals and to the reading and updating of the routing information and the like contained in such packets, typically in headers of such packets.

[0002] The advantages of packet-based optical transmission systems are well known, and the SONET standard is widely accepted as a suitable physical layer for optical transmission systems. Indeed, SONET is one of the many physical layers defined for ATM, which is itself a cell-based (i.e. packet-based) switching and multiplexing technology.

[0003] The rapid increase in transmission rates achieved by optical transmission systems far exceeds the capability of electronic processing of signals. Consequently, the limitation to data transfer rates results principally from delays introduced by electrical switching elements. However, these electronic and opto-electronic elements are required for performing switching and routing functions, and the conversion of high-speed optical data to electrical signals for the switching and routing operations is recognised as causing speed reductions.

[0004] There have been proposals to provide all-optical networks in which switching and routing take place in the optical domain. Thus United States Patent 5,541,756 proposes the use of a packet header with wavelength-coded data, in conjunction with a grating operating as a wavelength differentiator. Different wavelength signals within the optical header are deflected by the grating by different amounts to be incident upon photo-electric sensors positioned at different locations.

[0005] In a number of applications it is desirable to be able to change the contents of a header at a switch located at an intermediate position between where an individual packet is first created and its final destination. While effecting such a change in the electric domain is relatively easily accomplished, it is not so easy to accomplish this in the optical domain. A disadvantage of converting the contents of an optical packet (or just its header) into electrical domain, modifying it, and then using a laser/modulator to reconvert it back into the optical domain, involves a number of disadvantages. For instance, the process is not optically transparent, and so wavelength information is lost. Additionally the delay involved in conversion and reconversion is significant. Furthermore, the process requires the provision of more capacity in the router to process the signals passing through. If, on the other hand, one remains in the optical domain employing amplitude shift keying (ASK), which is the preferred format for optical data transmission, then, while it is easy to convert a high level ASK bit to a low level one merely by gating, conversion in the opposite direction (low level to high level) requires the provision of a facility for injecting light into the system at the location of the conversion.

SUMMARY OF THE INVENTION

[0006] The present invention is directed to the provision of a format of optical transmission network in which data packets, having a data-payload part and a non-payload that includes data packet routing information, can have their non-payload parts rewritten without having to have recourse to the use of an optical source at the location of such rewriting.

[0007] According to the present invention, there is provided an optical transmission network in which data packets, having a data-payload part and a non-payload that includes data packet routing information, are routed by an optical switch in different paths according to the routing information contained in the non-payload part of their respective data packets, and wherein the data-payload part of a data packet is transmitted as amplitude shift keying of an optical carrier while the non-payload part is transmitted as phase shift keying of the optical carrier.

[0008] Generally, but not necessarily always, the non-payload parts of such data packets take the form of data packet headers. There is thus no intrinsic reason why the non-payload parts of such data packets should not take the form of data packet footers.

[0009] Other features and advantages of the invention will be readily apparent from the following description of preferred embodiments of the invention, from the drawings and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

Figure 1 is a schematic representation of a data packet,

Figure 2 is a schematic representation of a switch for routing data packets according to the present invention,

Figures 3 to 8 are DPSK waveforms in the switch of Figure 2,

Figure 9 is a phase diversity receiver modification of the switch of Figure 2,

Figure 10 is a schematic representation of a zero-crossing detector that is an optional component of the switch of Figure 2, and

Figure 11 depicts an alternative topology of phase diversity receiver.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

[0011] Referring to Figure 1, a data packet indicated generally at 10 comprises an intensity modulated (ASK) data payload part 11, preceded by a differential phase shift keyed (DPSK) header 12 that contains routing information.

[0012] Figure 2 schematically depicts a switch (router) employed in an optical transmission network using the data packets of Figure 1. At the input of the switch, an optical tap 20 taps off a small proportion of the power of the received signal, and feeds the tapped power to a DPSK demodulator. Advantageously this demodulator may comprise a Mach Zehnder interferometer, and this is followed by a differential optical detector to convert the demodulated optical header into an electrical analogue. The interferometer comprises a pair of 2 $\times$ 2 3dB optical waveguide couplers 21a and 21b defining between them a pair of interference arms 22, one of which incorporates a delay 23 of magnitude τ_1 which is equal to one DPSK bit period. The differential detector comprises a pair of photodiodes 24 followed by an amplifier 24a. The output of amplifier 24a provides an input to a switch controller 25 that controls, via line 25a, the operation of an optical selector 26 directing an input to the selector 26 on line 27_0 to a selected one on its n output lines 27_1, 27_2, 27_3, ...27_n. Optical line 27_0 receives its input from the non-tapped output of tap 20 via a delay unit 28 that affords a delay of magnitude τ_2 sufficient to delay the arrival of each data packet 10 until after the selector 26 has had time to be set by the controller 25 in response to the detected signal it has received from the DPSK demodulator in respect of that data packet.

[0013] A simple form of router having no facility for rewriting the DPSK headers 12 of data packets 10 may be modified to provide this facility by incorporating an active phase adjuster 29 with the passive delay unit 28. This phase adjuster 29 is controlled over line 25b from the switch controller to switch into optical line 27_0 an additional delay corresponding to a phase difference $\phi = \pi$ in synchronism with selected DPSK bits of the data packet 10 as it propagates through the delay unit 28.

[0014] The total differential delay between the two interference arms 22 of the Mach Zehnder interferometer is such as to correspond to a phase difference substantially equal to $2N\pi$ or $2(n + 1)\pi$, where N is an integer. This ensures that the output of the interferometer produced by the interference of DPSK bits is confined substantially exclusively to the output directed to one of the detectors 24, or to the other one, according to the phase of the DPSK data bit concerned. Figure 3 depicts, as a function of time, the phase of an illustrative 12-bit DPSK header 12, while Figure 4 depicts the same header delayed by one DPSK bit period. Figure 5 depicts, as a function of time, the amplitude of the response of one of the photodetectors 24. (The amplitude of the response of the other photodetector; 24 is the inverse of the waveform of Figure 5.)

[0015] Figure 6 depicts, as a function of time, an illustrative waveform applied over line 25b to control the operation of phase adjuster 29. The illustrative waveform of Figure 6 is such as to produce phase inversion in bit periods 3, 6, 7, 8 and 11, and so will operate con the original DPSK header of Figure 3, reproduced as Figure 7, to provide the new header of Figure 8.

[0016] Satisfactory operation of the switch of Figure 2 requires tight control over the relative optical path lengths of the two interference arms 22 of the Mach Zehnder interferometer in relation to the wavelength of the incident light so as to avoid the phase quadrature condition in which the power of an incoming DPSK bit is divided substantially equally between the two photodetectors24 irrespective of the phase state of that bit.

[0017] In circumstances in which such tight control is either impractical or for some other reason not desired, a possible solution to this problem is to arrange to preface each header with a phase reference preamble. Such a preamble can be a DPSK signal or a signal of known phase, for instance a signal whose phase is midway between the two phases of the ensuing DPSK header. Within the interferometer is included active phase lock circuitry, such as a fast phase modulator and fast phase locked loop (neither shown). An alternative solution that may be preferred, because it does not require the use of the preamble or of the fast phase modulator and phase locked loop, involves replacing with a phase diversity receiver. A phase diversity receiver is like a simple Mach Zehnder interferometer receiver to the extent that both types of receiver rely upon employing interference effects to measure phase; the phase diversity receiver is distinguished from the simple Mach Zehnder interferometer receiver in that the former relies upon simultaneously employing two different interference conditions for its measurement so that, whenever either one of these interference conditions assumes a phase quadrature relationship, then for the whole time that that relationship is maintained, the other phase relationship is maintained in a phase relationship that is necessarily not a phase quadrature relationship.

[0018] An example of a suitable phase diversity receiver is schematically depicted in Figure 9. This diversity receiver uses all the components of the Mach Zehnder interferometer and differential detector of Figure 2, and additionally includes three further 2 × 2 3dB optical waveguide couplers 90, 91 and 92, a delay 93, and a further differential detector comprised by a pair of photodiodes 94. The magnitude of the delay 93 is such as to introduce a phase quadrature condition between the way in which power from the two interference arms 22 is interfered in coupler 21b and in coupler 92. Thus if the difference in optical path length, if any, between coupler 21b and couplers 90 and 91 corresponds to a phase angle α, then the corresponding difference in optical path length, if any, between coupler 91 and couplers 90 and 91 corresponds to a phase angle $(\alpha + \pi/2)$. In appropriate circumstances, adjustment of the delay 93 to its required magnitude may conveniently be effected by irradiating a portion of one of the interference arms with a controlled amount of intense UV light.

[0019] If the phase condition is such that coupler 21b divides the light equally between the two photodiodes 24 for a DPSK bit of one data significance, then it will similarly divide the light equally for a DPSK bit of the other data significance. Designating the output of the differential amplifier 24 as the I output, then, under these conditions the magnitude of the voltage swing, V_I produced by DPSK data bit significance transitions from this output is zero. On the other hand, this phase condition is also such that coupler 91 will apply the light substantially exclusively to just one of its diodes 94 for a DPSK bit of one data significance, and substantially exclusively to the other of its diodes 94 for a DPSK bit of the data significance. Designating the output of the differential amplifier 94 as the Q output, then, under these conditions the magnitude of the voltage swing, V_Q produced by DPSK data bit significance transitions from this output is at its maximum value. Generalising from this, if the phase condition is changed by a phase angle θ, then the voltage swings are given by $V_I = (V_I)_{max} \sin\theta$ and $V_Q = (V_Q)_{max} \cos\theta$. The I and Q output signals may then be processed to provide a demodulated DPSK output, V_{output} as follows:

$$\text{IF } V_1 >> V_Q \quad \text{THEN } V_{output} = V_I$$

$$\text{IF } V_1 >> V_Q \quad \text{THEN } V_{output} = V_Q$$

$$\text{IF } V_1 + V_Q > V_1 - V_Q \quad \text{THEN } V_{output} = V_1 + V_Q \quad \text{ELSE } V_{output} = V_1 + V_Q$$

This will always provide a demodulated output, though it will not distinguish between inverse DPSK sequences.

[0020] A particular feature of using a DPSK header in conjunction with an ASK payload is that the DPSK format is readily distinguishable at a detector from the ASK format, and so neither part constrains the format of the other part.. Thus for instance, a long sequence of data '0's or data '1's, if acceptable in the payload part of a data packet, can be tolerated by a detector of the headers of such packets. Such a sequence can be readily prevented from being spuriously interpreted at a detector of headers as part of a header by looking for zero-crossings. ASK data will produce modulation of the amplitudes of the outputs V_I and V_Q, but will never produce a zero-crossing. Conversely, each data bit significance transition of a DPSK header produces a zero-crossing in either or both of the outputs V_I and V_Q. Accordingly, a simple zero-crossing detector, for instance as schematically depicted in Figure 10, can tap a signal from the output V_{output} to provide an output employed to gate V_{output} so as to prevent it from reaching switch controller 25 except when DPSK signals (headers) are specifically detected as being present.

[0021] Figure 11 depicts an alternative topology of phase diversity receiver, one whose configuration of waveguides can be implemented in a compact integrated waveguide (so-called planar waveguide) format by virtue of its inclusion of a 'level-crossing' type intersection 110 of waveguides. In such an intersection optical power launched into any one of its four component waveguides is coupled virtually exclusively into the opposite waveguide (i.e. virtually no power is coupled into either of the adjacent waveguides of the intersection).

Claims

1. An optical transmission network in which data packets, having a data-payload part (11) and a non-payload (12) that includes data packet routing information, are routed by an optical switch (26) in different paths (27_1, 27_2, 27_3, ... 27_n) according to the routing information contained in the non-payload part of their respective data packets, and wherein the data-payload part of a data packet is transmitted as amplitude shift keying of an optical carrier while the non-payload part is transmitted as phase shift keying of the optical carrier.

2. An optical transmission network as claimed in claim 1, wherein the optical switch includes a reader of data packet non-payload parts, which reader includes a one bit differential delay optical interferometer (21a, 21b, 22, 23) feeding a photodetector (24).

3. An optical transmission network as claimed in claim 2, wherein the one bit differential delay optical interferometer is a phase diversity interferometer (21a, 21b, 23, 24, 90, 91, 92, 93, 94 (110)).

4. An optical transmission network as claimed in claim 2 or 3, wherein the output of the reader is fed to a logic unit (25) controlling a phase shifter (29) adapted to rewrite in response to signals from the logic unit selected bits of the non-payload parts of data packets.

5. A method of routing data packets in an optical transmission network, which packets have a data-payload part (11) and a non-payload (12) that includes data packet routing information, in which method the packets are routed in different paths by optical switches (26) in the network according to the routing information contained in the non-payload part of their respective data packets, and wherein the data-payload part of a data packet is transmitted as amplitude shift keying of an optical carrier while the non-payload part is transmitted as phase shift keying of the optical carrier.

6. A method as claimed in claim 5, wherein the non-payload parts of the packets are read at the switches by readers employing one bit differential delay optical interferometry.

7. A method as claimed in claim 6, wherein the readers employing one bit differential delay optical interferometry are phase diversily interferometers (21a, 21b, 23, 24, 90, 91, 92, 93, 94 (110)).

8. A method as claimed in claim 6 or 7, wherein the readers provide outputs which are applied to logic units (25) controlling phase shifters (29) which rewrite, in response to signals from the logic units, selected bits of the non-payload parts of data packets.

9. A router for routing data packets in a communications network, the data packets having a data-payload part (11) and a non-payload part (12) that includes data packet routing information, transmitted as phase shift keying of an optical carrier, the router comprising:

   means for reading the data packet routing information, and

   an optical switch for switching the data packets according to the data packet routing information, while maintaining at least the data-payload part in the optical domain.

10. Apparatus for use in a communications network, for modifying non-payload parts of data transmitted across the network, the non-payload parts being transmitted as phase shift keying of an optical carrier, the apparatus comprising:

   reading means for reading the non-payload parts of the data, and

   a phase shifter, for adjusting the phase of at least some of the phase shifted keyed non-payload part, to reunite this part, in response to an output of the reading means.

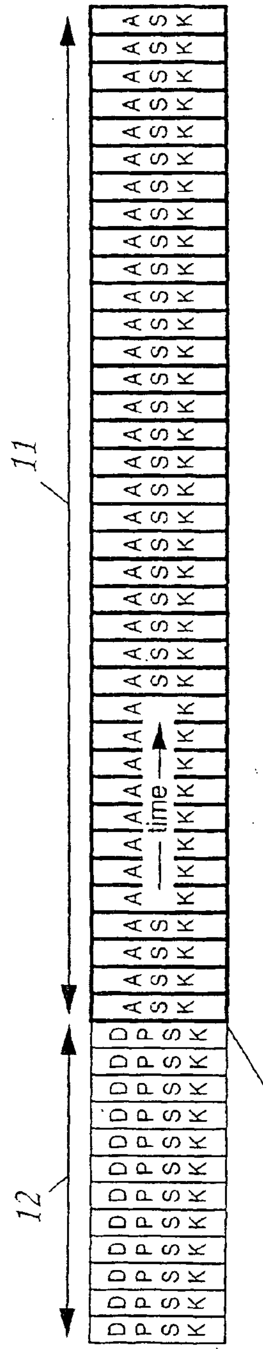
D
P
S
K
A
time
11
12
10

Fig. 1.

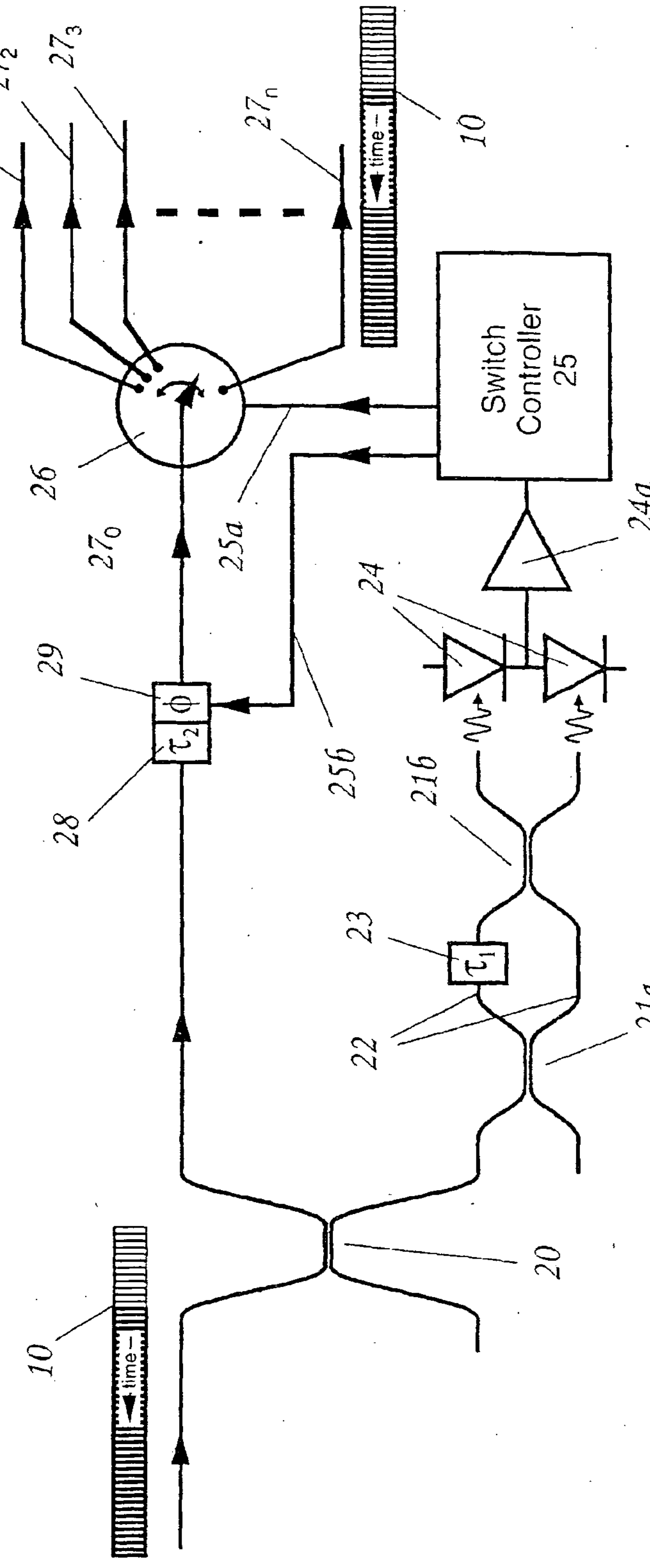
Switch Controller 25
time
10
20
21a
21b
22
23
24
24a
25a
25b
26
27₀
28
29

Fig. 2.

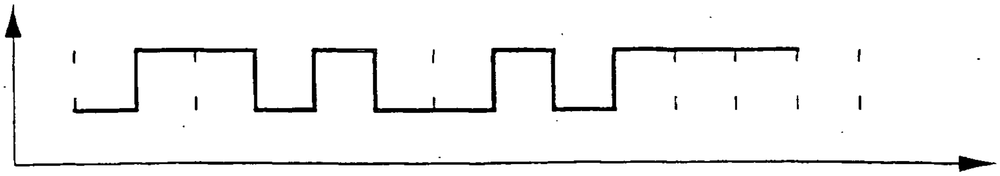

Fig. 3.

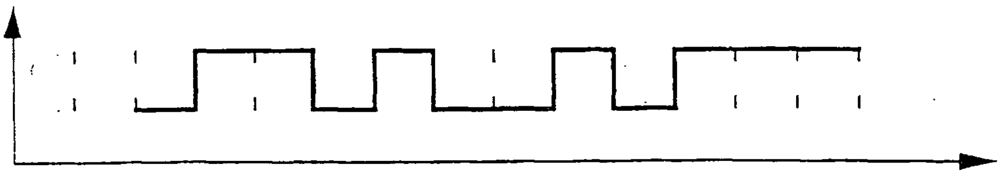

Fig. 4.

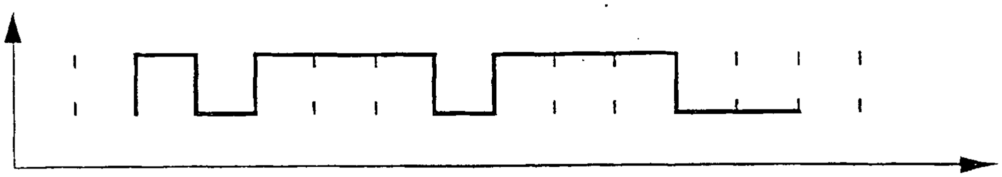

Fig. 5.

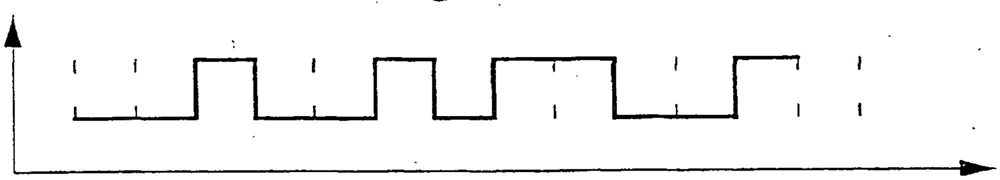

Fig. 6.

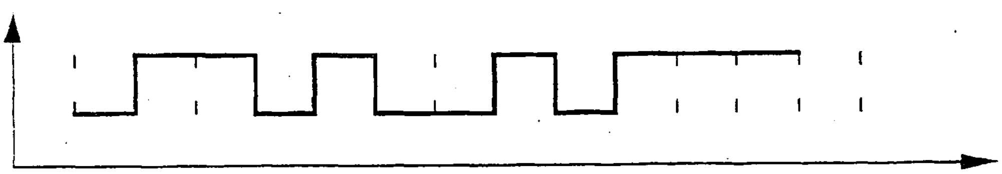

Fig. 7.

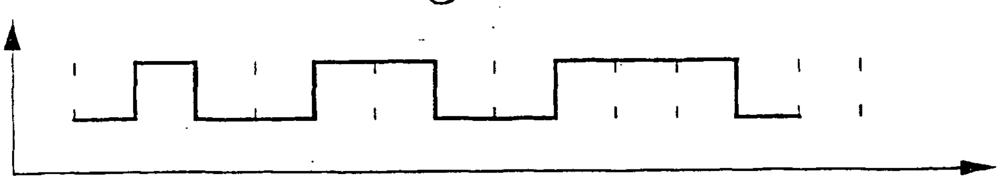

Fig. 8.

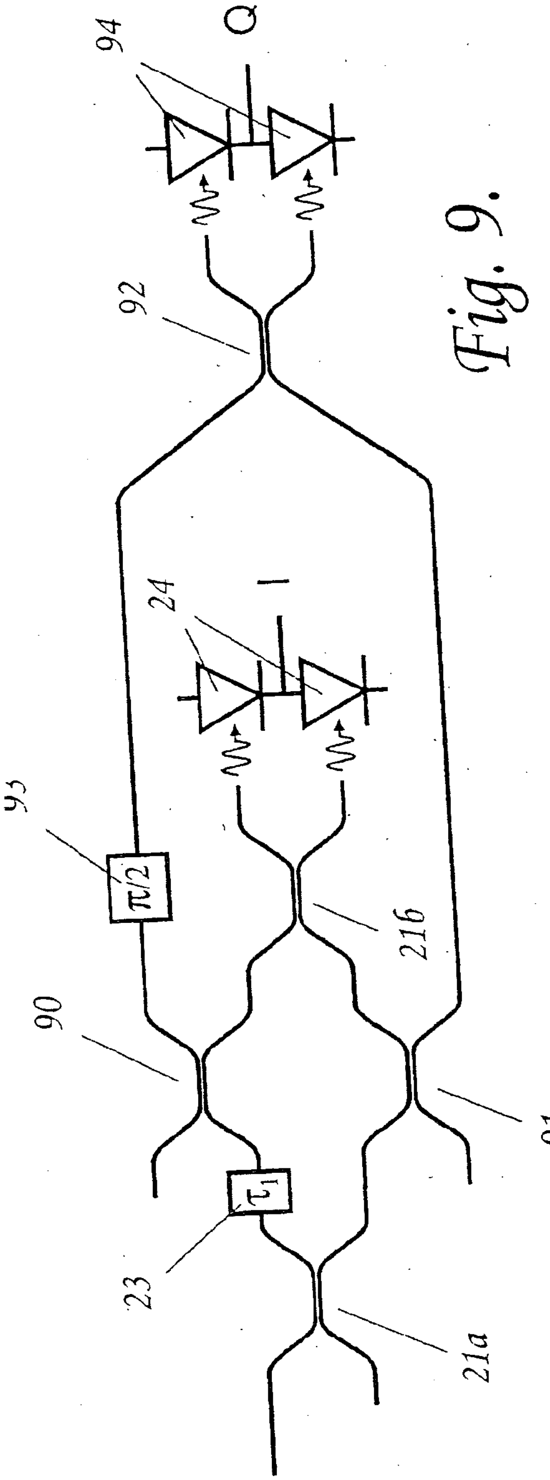

Fig. 9.

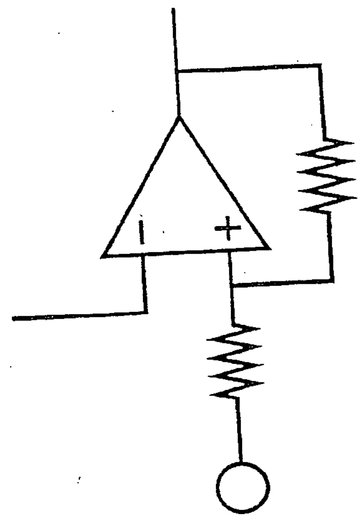

Fig. 10.

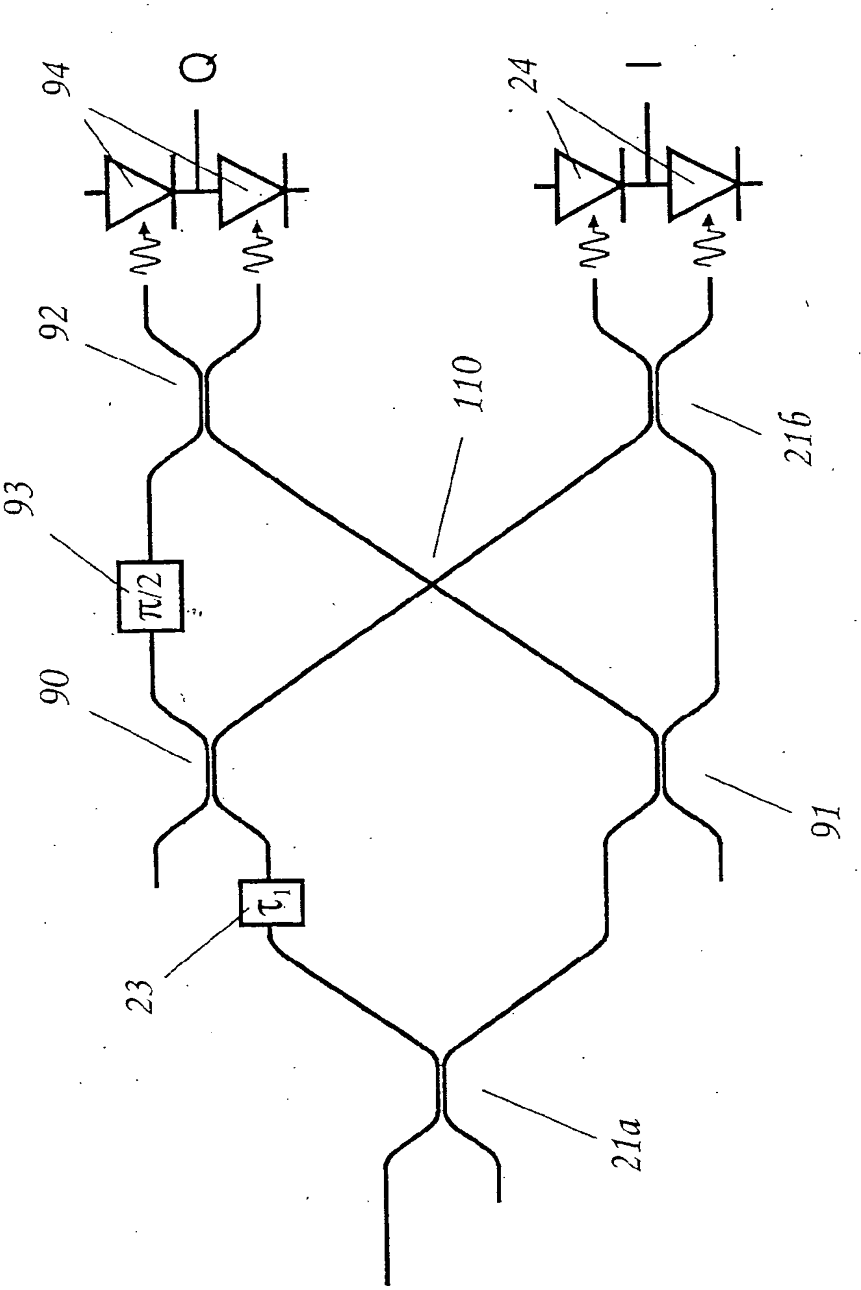

Fig. 11.